AMBIENT AIR TOXIC RELEASES AND ADVERSE PREGNANCY OUTCOMES IN ALLEGHENY COUNTY, PENNSYLVANIA

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Previous studies have shown that women exposed to certain air pollutants are at an increased risk for preterm delivery and/or delivering a low birth weight newborn. Preterm delivery and low birth weight are associated with an increased risk for morbidity and mortality. In an effort to better understand the impact of local environmental factors on pregnancy health, duration and outcomes, this study investigated the relationship of hazardous air pollutant chemicals released by local industries and the adverse pregnancy outcomes of preterm delivery and term low birth weight in Allegheny County, PA.

This study included 2,798 singleton birth records for deliveries that occurred in Allegheny County in January through March of 2004. The Toxic Release Inventory provided data for 2003 fugitive and stack air releases of all facilities in Allegheny County reporting air releases of lead and toluene. This data was used for determining proxy maternal exposure measurements. ArcGIS software was used to calculate the distance from each maternal residence to each TRI facility. The distances and reported total pounds of release from each facility were then used to calculate a total lead and toluene exposure value for every birth record. Binary logistic regression was used to assess maternal characteristics' effects on birth outcomes. Chi square tests were used to assess maternal characteristics and levels of exposure to lead and

toluene. Chi square tests and binary logistic regression were then used to assess pregnancy outcomes in relation to quartiles of exposure.

This study found that mothers with certain age, race, education, and marital characteristics were significantly associated with lower exposure levels of lead and toluene. However, exposure to higher levels of lead or toluene, as measured in this study, was not significantly associated with an increased risk for preterm delivery or term low birth weight.

Adverse pregnancy outcomes negatively impact an individual's immediate and lifelong health. Decreasing the incidence of preterm delivery and low birth weight are of great importance to public health. Research that helps to identify environmental determinants of adverse pregnancy outcomes is of vital public health significance.

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1.0 INTRODUCTION

Air pollution has been shown to have negative effects on the health of the general population [1-3]. Research suggests that the very young and the very old appear to be more susceptible than other age groups [4]. Exposures which occur earlier in life to chemicals found in air pollution are likely to have a greater impact on the health of an individual [5, 6]. More recently several studies have focused on the effects of maternal exposure to air pollution and adverse birth outcomes. The majority of these studies utilize air monitoring data as a proxy measurement for maternal exposures to air pollution and adverse pregnancy outcomes such as preterm birth, birth weight, and birth defects, as the outcome [4, 7-14].

In Allegheny County, Pennsylvania adverse birth outcomes continue to be a major health problem across all races, ages and socioeconomic groups with the largest burden of disease and mortality impacting African Americans [15, 16]. Despite the long standing efforts of local programs such as the Resource Mothers Program and Healthy Start, low birth weight and preterm delivery rates in Allegheny County continue to climb [16-18].

It is of vital public health importance to investigate other possible explanations for persistently high rates of preterm deliveries and low birth weights in Allegheny County. Low birth weight and prematurity contribute to newborn mortality as well as morbidities in the neonate period and have life-long consequences. In addition to examining access to care issues, quality of prenatal care and evaluating existing programs whose aim it is to address these health problems, it is also of vital importance to understand the role of the physical environment in which women live, conceive, and carry their pregnancy. This physical environment includes the maternal home, behaviors such as cigarette smoking, the environment of the surrounding neighborhood, workplace environment and the interactions of these environments through which women move. Frequently the quality of these environments, especially air quality, is out of individual control.

The purpose of this research is to study physical environmental factors and how such factors are associated with prenatal outcomes, both maternal health and the health of her developing fetus and newborn. Specifically, this study will examine ambient toxic releases, which contribute to local air pollution and birth outcomes of women living in Allegheny County. As the environmental exposure, this study uses toxic release data from industrial facilities in Allegheny County for the 2003 calendar year, as reported to the Environmental Protection Agency (EPA) through the Toxic Release Inventory (TRI) program. The outcome data includes birth certificate records from all births that occurred in the county during 2004. The study investigates the association between maternal exposure to locally released air pollution and resulting birth outcomes.

Investigating other potential causes of preterm delivery and low birth weight will guide future research as well as practice, policy and prevention initiatives in reducing the incidence of adverse birth outcomes.

2.0 LITERATURE REVIEW

2.1 DEFINITIONS

Low birth weight (LBW) is used to describe a newborn weighing less than 2,500 grams (or 5 lbs 8oz) at birth. A preterm delivery (PTD) resulting in a premature newborn is defined as a live birth occurring prior to 37 completed weeks of gestation.

2.2 ADVERSE BIRTH OUTCOMES

The preterm birth rate in the United States has been increasing in recent decades. Since 1981, the preterm birth rate has increased from approximately 9% to over 12% [15]. An evaluation of over 27,000 infant deaths occurring in 2002 with linked birth certificates indicated that preterm delivery was actually the leading cause of infant death, not congenital anomalies as was previously reported in earlier years. In this evaluation, 34.3% of all infant deaths in 2002 were attributable to PTD [19]. PTD plays an even larger role in our nation's high infant mortality rate if one considers neonatal mortality separately from infant mortality. In fact, PTD accounts for greater than 70% of neonatal deaths [20]. Research suggests that preterm labor and delivery are due to a complex, tangled set of social, health and genetic factors [15, 21]. Maternal smoking, periodontal disease, age, race, gynecological infections, socioeconomic status, education level, marital status and stress [20, 22-27] are all thought to impact the health of the woman and thereby the health of her uterus, cervix and/or placenta. Separately and synergistically, these factors can negatively affect the duration of pregnancy and contribute to preterm delivery. Additionally women who have a multi-fetal pregnancy (twins or triplets) [28] or who have a history of preterm birth are at an increased risk for PTD.

Late PTD, deliveries at 34 to 36 weeks gestation, are on the rise [20, 29]. Approximately three-quarters of all PTDs occur spontaneously, the remainder result from medical intervention [30]. Fertility treatments and an increase in the number of women delaying childbirth until a later age each contribute to the increasing rate of PTD. Another factor thought to increase PTD is continuous fetal monitoring which may lead to an increase in identifiable pregnancy complications that require medical interventions such as cesarean sections and inductions at earlier gestations. Lastly, the fear of litigation and poor pregnancy outcomes such as still-birth are also thought to be associated with PTD [28, 29, 31]. Despite the contribution of these known and suspected factors on the rising PTD rate, there remain unknown etiologies for preterm labor that result in PTD.

The incidence of LBW has also been on the rise in recent years in the United States. Nationally, the LBW rate has increased 13% from 1995 to 2005 [30]. LBW is believed to result from inadequate maternal weight gain, poor nutrition, placental insufficiency or other yet unknown etiologies. LBW is associated with multi-fetal pregnancy, maternal smoking, as well as a very young or much older maternal age [30].

LBW and prematurity greatly impacts not only the immediate viability of a newborn and health during the first year of life, but also the individual's health and wellness throughout the life span [27]. Premature delivery alone is thought to be responsible for close to half of the subsequent long-term neurological disabilities common in preterm infants [20]. Studies suggest that those born LBW and/or premature remain at an increased risk for lifelong ailments including heart disease, hypertension, and diabetes [32-34]. Birth outcomes have a significant effect on health status in the first year of life and subsequent health throughout adulthood, thus, methods to significantly reduce the numbers of adverse birth outcomes must be identified.

Despite clinical and community interventions, policies, briefings and national health goals, the incidence of LBW and PTD continue to climb in our country. Most recently, for the first time, prematurity has been listed as the number one cause for infant death, surpassing the category of congenital anomalies, which for decades has been listed as the biggest contributor to our country's infant mortality rate [19]. Other etiologies for pregnancy complications and adverse birth outcomes remain unclear and reproductive epidemiologists continue to search for determinants of pregnancy and fetal wellbeing and birth outcomes.

2.2.1 **Trends in birth outcomes in Allegheny County, PA**

In Allegheny County, PA there have been approximately 13,500 – 14,500 live births each year since 2000 [16]. During the 1970s to mid- 1980s, the county reported a reduction in the annual LBW incidence rates. Yet since the mid-1980s, the overall LBW trend has been rising. Throughout the 1990s and into 2003, Allegheny County and in particular the city of Pittsburgh, has experienced a higher LBW rate than Pennsylvania State and the nation. In 2003 the Allegheny County overall LBW rate was 8.7 per 1,000. This compares to a Pennsylvania state LBW rate of 8.1 and a US rate of 7.9. The distribution trend of LBW newborns is evident across all maternal age groups however LBW effects African-Americans more than Caucasians [16].

Table 1. LBW Incidence rates in Allegheny County, PA

LBW Incidence Rates 1996 - 2003	
Year	**Rate per 1,000**
2003	8.7
2002	8.5
2001	8.3
2000	8.1
1999	8.3
1998	7.6
1997	8.0
1996	7.5

Unfortunately, locally reported data do not include in-depth analysis of preterm deliveries in Allegheny County. Therefore, we do not know how many of these LBW newborns may be LBW due to a shorter gestation resulting from PTD. Overall, in the county in 2003, 10% of all Caucasian newborns and 16.7% of all African American newborns were born prematurely [16]. That same year, in comparison, 11.6% of newborns born in Pennsylvania were born premature and nationally 12.3% of all births were considered PTD.

2.3 AIR POLLUTION AND PUBLIC HEALTH

Since approximately 1950, epidemiological research has demonstrated the potential of adverse health outcomes related to exposures of environmental toxicants [35]. The Clean Air Act identifies 189 potentially harmful air pollutants that are designated as toxic or hazardous air pollutants (HAPs). HAPs are a diverse set of pollutants, some of which are prevalent in the natural environment while others are introduced through accidental releases and as by-products of modern industries. HAPs include metals, other particles, gases absorbed into particles and vapors from fuels and other sources [36]. Examples of HAPs include lead, mercury, nickel, selenium and manganese compounds, toluene, and inorganic arsenic compounds designated by the Clean Air Act. Both acute and chronic illnesses may result from exposure to HAPs, including nausea, cancer, and a variety of immunologic, neurologic, reproductive, developmental, respiratory and cardiovascular disorders [36, 37].

While studies in occupational settings and with animals have been conducted, few studies in humans have taken place to investigate HAP exposures to humans, including concentration levels of those exposures and health risks related to such exposures. Suh *et al.* and Mather *et al.* argue that not enough is known about the human health effects resulting from HAP exposures that are part of the everyday ambient environment [36, 38]. Mather states that many “linkages between environmental agents, individually or as mixtures, and health outcomes lack epidemiologic evidence and are postulated from laboratory animal studies” [38].

Investigating environmental determinants of health is complex in that the true exposure data is essential to linking environmental hazards and health outcomes [38]. Ideally, the exposure data would be at the individual level and would include a biomarker - such as a compound or its metabolites. When this is not possible, or in the case of a pilot study, surrogate or proxy exposure measurements are used which may include air monitoring data and ambient release data such as the TRI database of ambient toxic releases.

2.3.1 **Toxic release inventory**

The Emergency Planning and Community Right-to-Know Act (EPCRA) was established in 1986 as a response to an accidental chemical release from a plant in West Virginia. The Toxic Release Inventory program (TRI) was then initiated by the EPA in 1987. The EPCRA requires certain businesses, factories and industries to report the locations and quantities of chemicals stored on-site as well as data on releases and transfers of certain toxic chemicals from industrial facilities.

A facility must report to TRI if it is involved in certain types of manufacturing, metal mining, coal mining, chemical wholesalers, petroleum terminals and bulk stations, solvent recovery services, or any companies employing 10 or more full-time-equivalent employees and which process or manufacture more than 25,000 pounds or otherwise uses more than 10,000 pounds of any listed chemical during the calendar year [39].

Beginning in 1998, TRI expanded to include seven additional industries. These industries are metal mining (except iron and uranium), coal mining (except extraction activities), electric utilities (those that burn coal or oil), RCRA Subtitle C treatment, disposal, and recycling facilities, petroleum terminals, solvent recovery facilities, and chemical distributors [40].

Currently almost 650 chemicals are part of the reporting system. In recent years new industry sectors have been added to the list of those required to report their releases and additionally the EPA has reduced the reporting threshold for certain chemicals so that the public may be aware of the full scope of releases.

Releases reported to TRI include air, water, underground, or land release. Fugitive air emissions include all releases to air that are not released through a confined air stream. Fugitive air emissions include equipment leaks, evaporation losses from surface impoundments and spills and releases from building ventilation systems. Point source air emissions, also known as stack emissions, refer to air emissions occurring through confined air streams, such as stacks, vents, ducts, or pipes [39]. Stack air emissions generally spread over a larger area than fugitive emissions.

The goal of the TRI system is “to empower citizens, through information, to hold companies and local governments accountable in terms of how toxic chemicals are managed” [39]. Chakraborty states that TRI data “has emerged as a popular and useful data source for environmental monitoring and risk assessment” [41].

2.3.2 **Adverse birth outcomes**

Studies have examined air pollution and its effect on birth outcomes in California, Massachusetts, and Texas, as well as the general northeast United States and in several other countries. Studies have found relationships between PM_{10}, $PM_{2.5}$ or CO and PTD or LBW [4, 10]. The majority of these studies used air monitoring devices that capture and measure a reading of the local air, for example, of ozone, PM_{10}, $PM_{2.5}$ or CO, as the surrogate for maternal exposure. Unfortunately, such air monitoring devices do not measure and record the types of metals and chemicals released from local industries included in the TRI. Therefore, if environmental health researchers are interested in identifying the effects of local industries’ actual ambient releases on the health of the local population, other proxy exposure measurements are necessary.

Curry and Schmieder used TRI data and the Vital Statistics Natality and Mortality files to examine the effects of ambient releases of toluene, lead, and other toxic releases on gestation, birth weight and infant death [13]. The study specifically considered lead and toluene due to their classification as developmental toxicants. By aggregating TRI release and birth outcome data at the county level, the study analyzed the effects of TRI fugitive and stack releases on birth outcomes for all counties with a population size of 100,000 or larger. The study found negative effects of prenatal exposure to TRI releases on birth outcomes including length of gestation and birth weight as well as infant death.

Lead is a heavy metal and a long known potent neurotoxin that accumulates in bone and soft tissues over time. Lead that is emitted into the environment can be inhaled, or later ingested from contaminated soil or dust, after which lead quickly enters the blood stream . Lead readily passes through the placenta and the central nervous system is particularly sensitive during development [42]. The mother's blood lead level can be less than the identified toxic level yet still have negative effects on the fetus. This puts the developing fetus at an increased risk should the pregnant women be exposed to lead. Preterm birth, decreased birth weights and fetal death have been associated with higher maternal prenatal blood lead levels [35, 43]. Lower IQ, cognitive deficits, behavioral problems, renal damage, reduced growth in height, and reduced bone growth are associated with lead exposure in either the mother or the young child. Lead exposure can damage the central nervous, renal, cardiovascular, reproductive and hematological systems [35] and has been found to delay puberty when children are exposed to high doses.

While levels of lead in the air have decreased by 91 percent between 1980 and 2007, certain business sectors still emit significant quantities of lead or lead compounds from their work sites. The highest levels of lead in the air are usually found near lead smelters. Other stationary sources of lead are waste incinerators, utility sites such as electricity generators and lead-acid battery manufacturers [44].

Toluene is also known as methylbenzene or phenylmethane. It is an aromatic hydrocarbon and considered a Volatile Organic Compound (VOC). Toluene accounts for the vast majority of VOC ambient emissions [13]. Toluene is a widely used industrial chemical that is produced during petroleum refining and as a by-product of styrene manufacture and coke-oven operations [45]. Approximately 90% of toluene is produced as part of aromatic mix with xylene and benzene which is used for blending gasoline [46]. The other approximate 10% of toluene is used as a solvent in paints, coatings, inks, glues and consumer products [45]. One mechanism through which toluene can enter the human body is by vapor inhalation from the liquid evaporation. In addition to its industrial uses, toluene is misused as an inhalant drug similar to other solvents misused for their intoxicating properties.

Organic solvents, like toluene, cross the placenta easily [47, 48]. Animal studies and human studies, including occupational exposure studies and maternal toluene-abuse studies, form the base for current knowledge on the effects of toluene on the fetus. Studies have found that women exposed to toluene are at a greater risk of having a fetus with intra-uterine growth retardation, small for gestational age, microcephaly or malformations. After fetal exposure, infants are then thought to be at increased risk for growth deficiency, developmental delays, and continued microcephaly from intra-uterine toluene exposure [49].

2.3.3 **In and around Pennsylvania**

Allegheny County, located in southwest Pennsylvania, has a total area of 745 square miles. As of the 2000 census the population was approximately 1,300,000. Despite a massive and ongoing cleanup following the collapse of the steel industry, Allegheny County still struggles with high amounts of air pollution from local industries. Pittsburgh's long history of intensive industrial facilities and poor air quality led to a passionate effort to monitor local air quality. This monitoring took on many forms and names over the years and was addressed by various community, political, governmental and environmental groups and agencies. A historic review of the air monitoring efforts in Pittsburgh can be found in Longhurst's "1 to 100: Creating an Air Quality Index in Pittsburgh" [50]. A handful studies have been conducted in and around south-western Pennsylvania investigating the quantity and type of ambient air pollution. A few other studies have gone one step further to investigate the effects of ambient air pollution on health outcomes.

The intensive Pittsburgh Air Quality Study examined several sources of air pollution data for particulate matter and investigated pollution modeling types, ozone patterns, weather effects on pollution, day-to-day trends, as well as instrument design and evaluation [51]. The study did not directly seek to link air pollution data with health outcomes, but rather sought to quantify pollution levels and evaluate measurement methods. It is interesting to note that this report on a seemingly comprehensive study does not include any measures or calculations for the contribution of TRI releases on local air pollution levels.

A 2005 study examined the association between ambient air pollution and hospitalization rates for congestive heart failure in Pittsburgh, PA. The study explored PM_{10}, CO, SO_2 and NO_2 and found there was a positive association between same day air pollution levels and the rate of admission to local hospitals for cardiac related conditions [52]. The study concluded that increases in air pollution from vehicular traffic negatively impacted already cardiac-compromised patients.

One study using TRI data investigated the national geographic distribution of potential risks from ambient toxic releases. TRI data from 2000 TRI showed that Ohio ranked among the highest in all risk categories and West Virginia was determined one of the most "hazardous" states for emissions weighted by population and area of the state. The same study reported that Pennsylvania was ranked fifth highest in total TRI air emissions for 2000 calendar year [41].

Sagiv *et al.* conducted a time series analysis of air pollution and preterm deliveries using birth certificate data from 1997 to 2001. The study included four Pennsylvania counties, one of which was Allegheny County. The study results found that exposure to particulate matter (PM_{10}) and sulfur dioxide (SO_2) increased the risk for preterm delivery [7].

It is important to note that the majority of studies mentioned above all rely on air monitoring data for the measurement of exposure to air pollution. Most studies do not utilize TRI release data in their assessment of air pollution's impact on the health of the local population. Allegheny County Health Department's 2007 Air Quality Quarterly Report analyzed data from air monitors only and did not examine readily available TRI data take into account the quantity or type of releases from local industries [53].

The potential of health consequences from local air pollution on women and their pregnancies is a cause for an investigation of the toxic ambient releases that contribute to local air pollution and its impact on maternal and fetal health.

2.4 USE OF GIS IN ENVIRONMENTAL HEALTH RESEARCH

Geographic Information Systems (GIS) have been used over the past two decades in a variety of spatial health analyses [54, 55]. GIS is a useful tool for examining hazard, exposure and health outcome data. In the field of environmental epidemiology studies, GIS are being used with increasing frequency [56]. Perhaps most useful is the application of GIS software, such as ArcGIS by ESRI, to evaluate the effects of environmental exposures on individual or population health outcomes.

Nuckols, Ward and Jarup (2004) concisely describe the appropriateness of spatial analysis in environmental exposure studies:

> Environmental epidemiology is an area of epidemiology concerned with the study of associations between environmental exposures and health outcomes, with the purpose of further understanding the etiology of disease. The term “environmental” implies a spatial context. Thus, the study of interactions between humans and their environment requires spatial information and analysis. Geographic information system (GIS) software allows environmental and epidemiologic data to be stored, analyzed, and displayed spatially [56].

Cromley and McLafferty (2002) summarize that:

> GIS analyses can contribute to epidemiological studies by modeling the geographic distribution of contamination zones composited across a range of contaminants and overlay these with distributions of locations where susceptible populations live, work, attend school, and engage in other activities [54].

In the hazard-exposure-outcome model of environmental epidemiology, GIS and spatial analysis play an important role in the hazard identification and subsequent exposure approximation. This is especially true when direct quantitative data on individual exposure is not available or the study design necessary to measure the exposure and/or dose at which an adverse affect is obtained is not ethical. In these situations, GIS can be used to determine a proxy or surrogate exposure, to study either communities within a designated spatial region or the individual level.

GIS have been used in studies of human health and vector-borne diseases, infectious diseases, well contamination, release and transport of chemicals, water surface temperatures and microbiological climates along the coasts [55]. An excellent review of the history and use of GIS in a variety of studies can be found in Cromley's 2003 article "GIS and Disease." Cromley also reports that "environmental inequity studies are beginning to explore more fully the relationships between concentration of TRI facilities in particular neighborhoods and the degree of hazard associated with those facilities" [55].

GIS and spatial analysis have also been used in studies investigating determinants of adverse birth outcomes. Some of these studies use spatial analysis when examining environmental exposures to air pollution while others use spatial analysis when examining trends within and between census tracks, neighborhoods or states. In a study of neighborhood-level variables that may increase risk for LBW, English et al. used spatial analysis to look for possible neighborhood predictors of LBW. They used approximately 16,000 birth records to create a continuous surface of LBW change with a GIS and were then able to determine statistically significant "hot spots" of LBW for further analysis of neighborhood-level variables from census data and individual-level variables from birth certificate data [57].

Many public health studies which utilize GIS exhibit a shared tendency to aggregate health outcomes at the neighborhood or census track level when analyzing the environmental effects on populations. An example is Currie's work discussed above [13], in which TRI release data, birth outcomes data and death data were all aggregated at the county level. Another alternative frequently used is setting the centroid of a census track as the geographical point from which distances to environmental exposures are measured. Then all health outcomes in that census track are assigned that proxy location or distance measurement. Neither of these methods seriously consider individual characteristics or geographic location and therefore only provide aggregated exposure measurements or outcomes.

In environmental exposure analysis there can be limitations when aggregated demographic data, such as census tract or block data, are used. “The use of individual geocoded locations provides a more accurate characterization of the exposed population and more reliable comparisons among subgroups” [58].

2.5 GAPS IN KNOWLEDGE

To date, maternal exposures to TRI ambient toxic releases and the subsequent effects on birth outcomes have not been explored in Allegheny County. National as well as international environmental health research has focused on using air monitoring data as a proxy exposure measurement in birth outcomes research. While air monitors do measure ambient lead concentration, these studies have focused primarily on particulate matter and carbon monoxide and have not examined the affect of lead in the ambient environment nor its impact on birth outcomes. As air monitors do not measure the local releases that are reported to the TRI, such as toluene or the concentration of toluene in the air, other surrogate measures of exposure are needed to investigate the effects of TRI releases on the health of local women, their pregnancies and newborns.

3.0 MATERIALS & METHODS

3.1 EXPOSURE ANALYSIS

3.1.1 TRI data

For this study ambient toxic release data was obtained from the TRI via direct download from the Right to Know Network (RTK) website. The RTK website obtains TRI information directly from the EPA and makes the TRI data publically available from an easy to use database. The annual release data for 2003 was obtained for all TRI sites in Allegheny County required to report release data. The TRI data file includes an assigned longitude and latitude for each TRI facility. This longitude and latitude were used to geographically place the facilities within a shape file in ArcGIS for analysis.

The RTK Network TRI database was searched for TRI sites physically located in Allegheny County in the year 2003. Individual chemicals were searched by name such as "Lead*" and "Toluene*." The "*" allows for any releases including the words lead or toluene to be found, including compounds, such as "lead compounds." Sites that did not have *ambient* releases of these chemicals were removed from the list, leaving 20 lead and 18 toluene emitting sites. Other facilities in Allegheny County may store, transport or release via water or ground lead, manganese or toluene, but for 2003 did not report emitting these two toxic releases via stack or fugitive air releases. For this analysis, the fugitive and stack air releases for lead and toluene were combined for a 'total air release' for lead and toluene. This total air release was the measurement of release used for exposure analysis in GIS.

Birth outcomes are likely to be highly influenced by conditions during the period of pregnancy. Therefore, as the exposure to local air pollution, this study uses the reported lead and toluene 2003 annual release total, reported as pounds per year. Following this 2003 time period of exposure, the study includes births occurring between January 1st and March 31st of 2004. The study assumes that women were exposed for approximately six to nine months of their respective pregnancies, accounting for at least half of the duration of each pregnancy.

Table 2. Maternal exposure to TRI releases

2003 approximate duration of ambient lead and toluene exposure during pregnancy												2004 month in which birth occurred			
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
												X			
													X		
														X	

3.1.2 **Using GIS to estimate exposure**

For this study ArcGIS 9.3 software was used to determine the proxy maternal exposure to ambient lead and toluene. Using the assigned longitude and latitude for each lead and toluene TRI site, a shape file was created in ArcGIS which overlaid a shape file of Allegheny County.

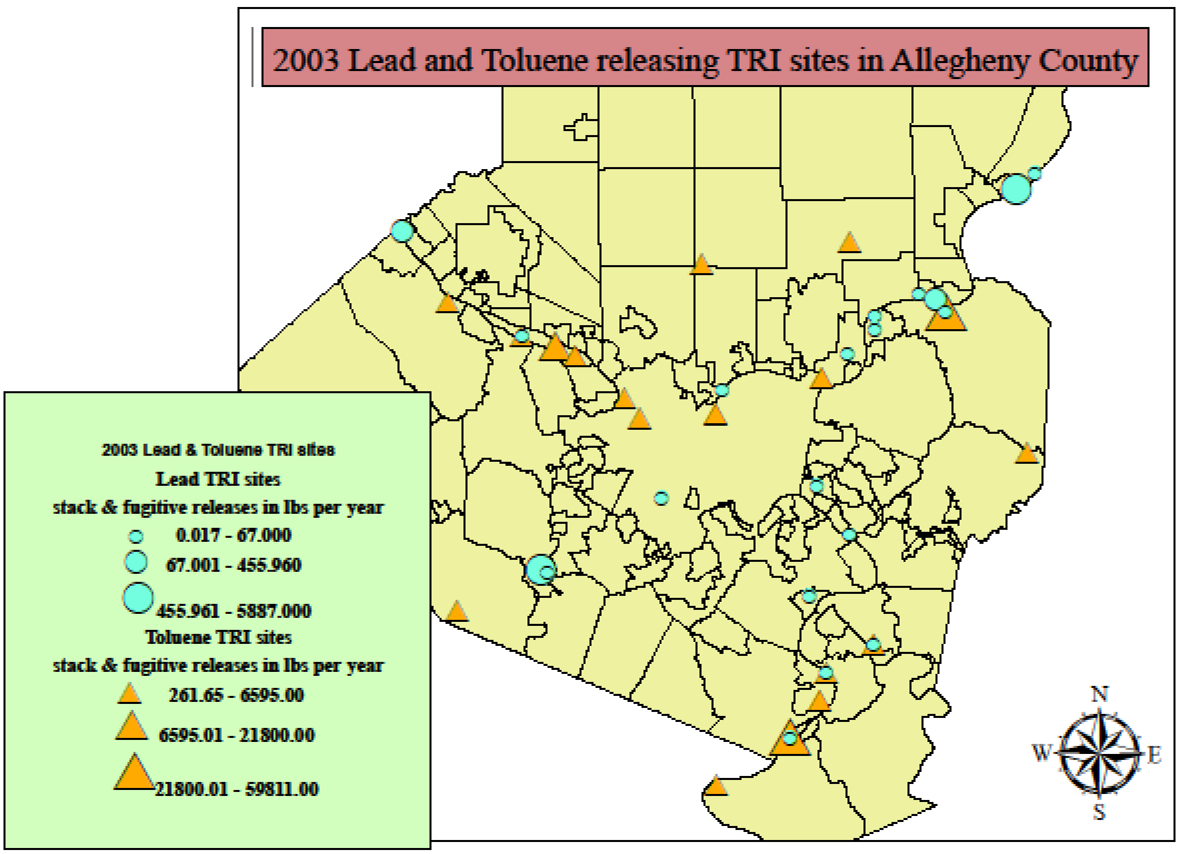

Figure 1. Map of lead and toluene releasing TRI sites in Allegheny County for 2003

This shape file shows the geographic location of each lead and toluene TRI site within the county. Within ArcGIS, each TRI location contains its own total air release data for lead and toluene, which equals the combined stack and fugitive air releases reported for 2003.

As the lead and toluene release data is in total pounds over the course of the year, and it would be incorrect to assume that any woman living in the county would be exposed to the full amount of the ambient release, regardless if she lives near or far from a particular TRI site. Therefore, the following methods were used to calculate maternal exposures to ambient lead and toluene released from TRI sites.

The individual woman's exposure to the release was calculated considering the release as being dispersed in a 360 degree circle emanating from the TRI site, with the exposure decreasing over distance away from the TRI site. An example can be seen in Figure 2 below.

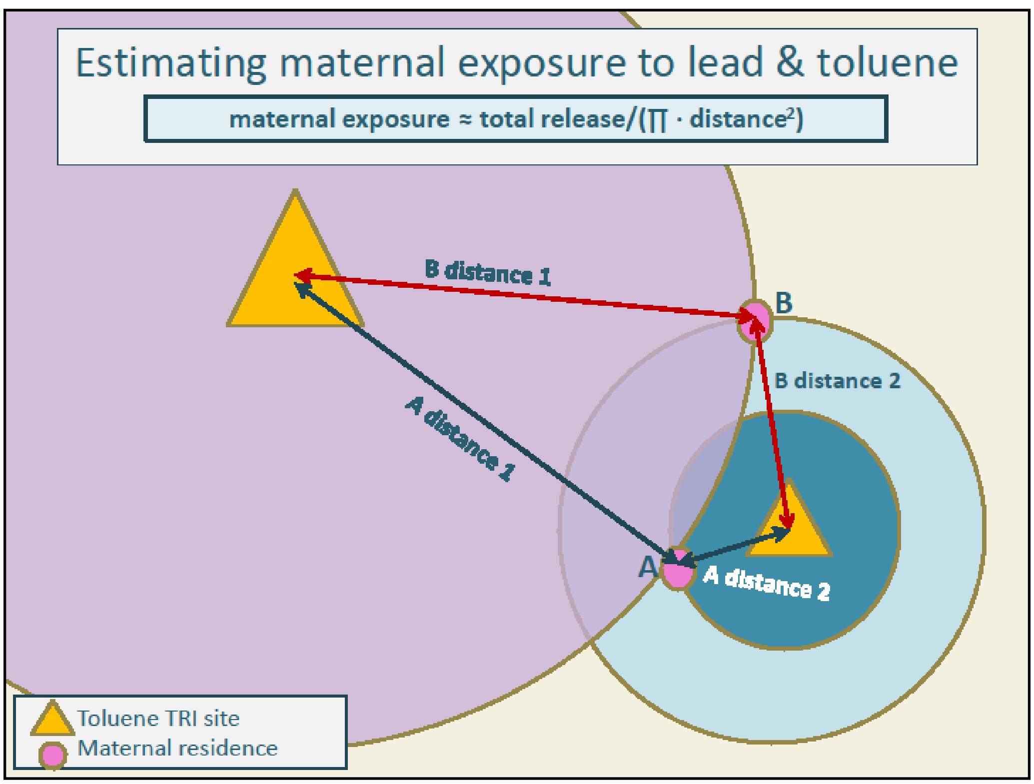

Figure 2. Method for estimating maternal exposure to TRI releases

An exposure measurement from each TRI facility was calculated for each woman. Each of the 2,798 maternal residences, identified in the birth certificate data as individual maternal longitudes and latitudes, were then made into a shape file in ArcGIS. An application of Hawth's tools was then used to measure the distance from each maternal residence location to each TRI lead release site. The values were put into a matrix in which each column was a TRI release and each row was a maternal residence. A separate Excel sheet contained the total air release data for each TRI release site. This method was repeated for toluene. The distances, in meters, and the total release amount from each TRI site (in pounds per year) were then entered into the following equation to determine maternal exposure from each TRI site in the county:

$$\text{maternal exposure} \approx \text{total release}/(\prod \cdot \text{distance}^2)$$

Each maternal residence then had 20 exposure measurements for lead and 18 exposure measurements for toluene. The maternal exposure measurements for each of these TRI release sites were then summed across the columns to get a cumulative exposure to both lead and toluene for each woman.

3.2 STUDY POPULATION

All birth certificate data was originally collected at the place of delivery, sent to the health department, and then synthesized and de-identified by the state health department. Additionally, the state health department assigned each maternal address longitude and latitude coordinates for future spatial analysis studies. The 2004 Allegheny County birth certificate data was obtain from the state health department by Graduate School of Public Health Professor Ravi Sharma. The IRB approved use of the de-identified data for an "environmental, neighborhood and socioeconomic determinants of birth outcomes" study, IRB #PRO07060024. Birth certificate data was cleaned and analyzed using the statistical software package SPSS Statistics 17.0.

Variables utilized from the 2004 birth certificates include maternal age, race, height, pre-pregnancy weight, marital and smoking status, education level, parity, longitude and latitude coordinates matched for the maternal address, newborn's date of birth, gestation at birth, birth weight in grams, occurrence of premature rupture of membranes (PROM), and history of preterm birth with prior pregnancies.

Live singleton births born between January 1, 2004 and March 31, 2004 in Allegheny County, Pennsylvania were eligible for inclusion into this study. There were 13,203 total live births in 2004. Of these births, 3,240 occurred January 1 through March 31, 2004. 12.1% of these 3,240 births were PTD, 8.8% were born LBW and 2.7% were term LBW. Twin, triplet and quadruplet birth records were excluded (n=136) leaving 3,104 birth records. Once these multi-fetal pregnancies were removed from the study sample, the PTD percentage dropped to 9.7% and overall 6.8% were born LBW, with 2.5% of the term deliveries qualifying as LBW. Birth records for which the state health department could not match the given maternal address to longitude and latitude coordinates were then excluded from the study. This required excluding 306 birth records that were unmatched, leaving a total of 2,798 birth records for analysis.

Maternal race and Hispanic origin were collapsed into a single variable with three mutually exclusive categories (White, Black, and Other). Maternal education, originally a variable with eight categories, was collapsed into three levels: completed less than or up to 11th grade, completed a 12th grade diploma or GED, and completion of any post-secondary education including all levels of college education. Maternal age, originally a continuous variable, was categorized as 12-18 years, 19-35 years and 36-50 years old.

3.3 STATISTICAL ANALYSIS

Initial exploration of lead and toluene exposure values indicated they were not normally distributed. For analysis of more normally distributed lead and toluene exposure, the exposure values were $\log^{10}$ transformed. Initial comparison of the exposure values as continuous variables with the two birth outcomes proved similar to the logged exposure values. The $\log^{10}$ lead and toluene exposure values were split into four equal quartiles of exposure, with the first quartile as the lowest exposure quartile and therefore used as the referent category in all analyses.

As the dependent variables LBW and PTD are dichotomous, binary logistic regression was used to determine an odds ratio for each maternal independent variable and the birth outcomes term LBW and PTD (Tables 6 and 7). Maternal independent variables and lead and toluene quartiles were then analyzed using chi-square test (Table 8). The percentages of normal gestation and birth weight, PTD and term LBW records within each quartile of exposure were calculated and assessed with a chi-square test (Table 9). Finally, quartiles of exposure and birth outcomes were assessed using binary logistic regression for unadjusted and adjusted odds ratios (Tables 10 and 11).

4.0 FINDINGS

4.1 LEAD AND TOLUENE

The highest lead emitting TRI site in Allegheny County emitted approximately 5,877 pounds of lead over the 2003 calendar year. The mean release from all lead emitting sites was 529.66 lbs/year. The highest toluene emitting TRI released approximately 59,811 pounds during 2003. The mean release for all toluene sites was approximately 8,240 lbs/year. Information on the lead and toluene TRI sites is contained in Tables 3 and 4.

Estimated maternal exposures to lead ranged from .000003 - .00348 lbs per year/m^2. Estimated maternal exposures to toluene ranged from .000037 - .024174 lbs per year/m^2. Histograms of the calculated maternal lead and toluene exposure values are shown in Figures 3 and 4.

Table 3. Ambient lead releases in 2003

Lead and Lead Compounds Ambient Releases from TRI sites Allegheny County, PA 2003			
	Fugitive Air Releases	Stack Air Releases	Total Air Releases
Total number of sites	20	20	20
Minimum release	0	0	0.0172
Maximum release	5,386.000	859.000	5,887.000
Mean	423.153	106.503	529.656
Standard deviation	1,293.140	221.359	1,464.628

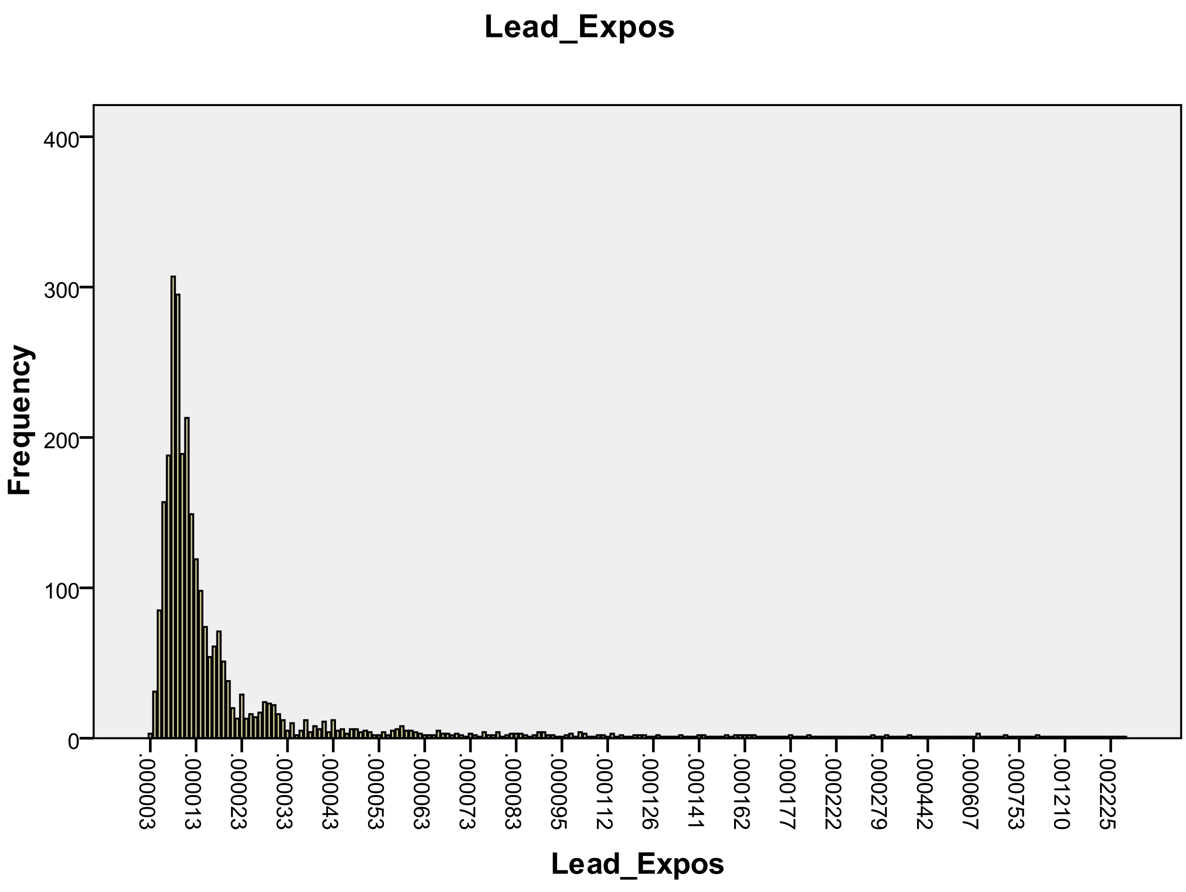

Figure 3. Histogram of estimated maternal lead exposure levels in lbs per year/m^2

Table 4. Ambient toluene releases in 2003

Toluene Ambient Releases from TRI sites in total pounds per year Allegheny County, PA 2003			
	Fugitive Air Releases	Stack Air Releases	Total Air Releases
Total number of sites	18	18	18
Minimum release	0	0	261.650
Maximum release	18,781.000	41,935.000	59,811.000
Mean	2,458.969	5,781.233	8,240.203
Standard deviation	5,116.159	12,802.596	16,137.264

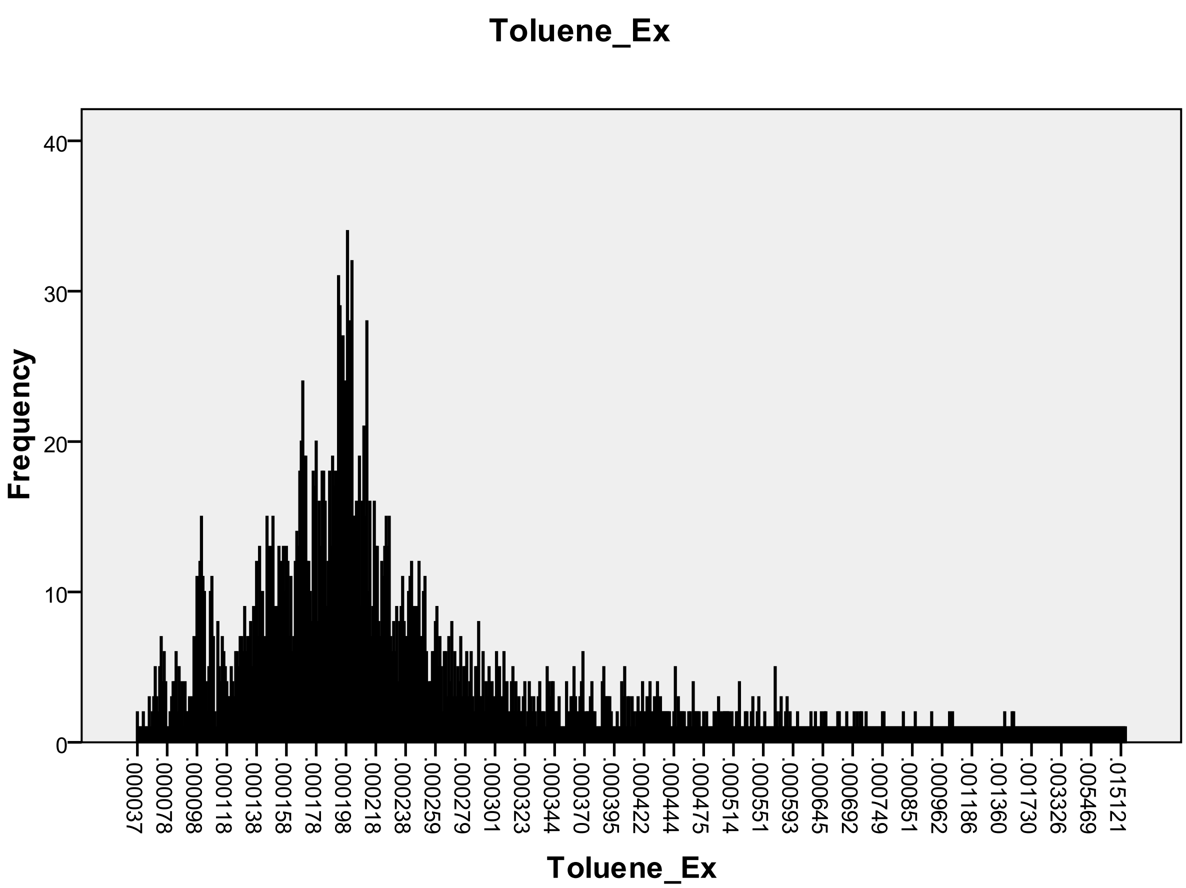

Figure 4. Histogram of estimated maternal toluene exposure levels in lbs per year/m^2

4.2 BIRTH OUTCOMES

It is important to note that the Allegheny County births which occurred in January, February and March of 2004 (n=3,240) had a higher proportion of LBW newborns than both the state and national levels for the same year. Additionally, this Allegheny County sample also had a higher percentage of PTDs than Pennsylvania State.

Table 5. 2004 US, State and Allegheny County LBW and PTD percentages

	United States	Pennsylvania	Allegheny County January - March 2004
LBW	8.1%	8.2%	8.8%
PTD	12.5%	11.8	12.1%

The dependent outcome variables term LBW and PTD are dichotomous, therefore binary logistic regression was used to determine an odds ratio for each maternal characteristic and the birth outcomes term LBW and PTD. Resulting odds ratios, significance levels and confidence intervals are seen in Tables 6 and 7. Referent categories for analyses of associations between maternal characteristics and birth outcomes were based on previous studies and published literature [59]. For analysis of the three age categories, the 19-35 year olds were used as the referent category. For analysis of education level, college education - the highest category, was used as the referent point. Using white ethnicity as the referent category, those of African-American race had an increased odds ratio of 2.3 (p=.003) for term LBW and an OR of 1.68

(p=.000) for PTD. Being of African American ethnicity, having a 12th grade diploma or GED as the highest obtained education level, smoking, premature rupture of membranes or having a medical history including a pervious preterm birth significantly increased the odds for PTD. Prenatal care in the first trimester and being married were protective against PTD. African American ethnicity, education attainment less than post secondary education, or smoking increased the odds for a term LBW newborn. Marriage was highly protective against term LBW. In this study sample, maternal age and parity do not appear to be associated with increased odds of experiencing either PTD or term LBW.

Table 6. Maternal characteristics of study sample and association with LBW

	Total* n=2,798	Normal gestation & birth weight n=2,456	**Term LBW** n=63	OR^	95% CI	p
Age						
<19	153 (5.5%)	130 (85.0%)	6 (3.9%)	1.886	.794, 4.479	.151
19 – 35	2266 (81.0)	2003 (88.4)	48 (2.1)	[1.00]	Referent	.353[a]
>35	379 (13.5)	323 (85.4)	9 (2.4)	1.124	.547, 2.310	.750
Race						
White	2062 (73.7)	1842 (89.4)	36 (1.7)	[1.00]	Referent	.010[a]
Black	596 (21.3)	490 (82.2)	23 (3.9)	2.259	1.328, 3.843	.003
Other	140 (5.0)	124 (88.6)	4 (2.9)	1.655	.581, 4.718	.346
Previous Birth						
No	1212 (43.3)	1057 (87.2)	35 (2.9)	1.643	.994, 2.716	.053
Yes	1575 (56.3)	1392 (88.5)	28 (1.8)			
Marital Status						
Not married	962 (34.4)	798 (83.0)	37 (3.8)	2.775	1.670, 4.612	<.0001
Married	1830 (65.4)	1652 (90.3)	26 (1.4)			
Education Level						
≤11th grade	274 (9.8)	233 (85.0)	13 (4.7)	3.130	1.612, 6.077	.001
12th or GED	587 (21.0)	490 (83.5)	20 (3.4)	2.216	1.249, 3.933	.007
Postsecondary	1915 (68.4)	1715 (89.6)	30 (1.6)	[1.00]	Referent	.001[a]
Smoking Status						
No	2344 (83.8)	2092 (89.3)	41 (1.7)			
Yes	417 (14.9)	338 (81.1)	21 (5.0)	2.979	1.742, 5.094	<.0001
PNC in 1st Trimester						
No	269 (9.6)	220 (82.1)	9 (3.3)	1.654	.798, 3.426	.176
Yes	2146 (76.7)	1918 (89.4)	44 (2.1)			
History of PTD						
No	2737 (97.8)	2417 (88.4)	60 (2.2)			
Yes	61 (2.2)	39 (63.9)	3 (4.9)	2.308	.703, 7.573	.168
PROM						
No	2691 (96.2)	2400 (89.3)	59 (2.2)			
Yes	107 (3.8)	56 (52.3)	4 (3.7)	1.732	.617, 4.861	.296

* Independent variable totals may not equal 100% of study sample due to missing/unknown values.

^ Assessed using binary logistic regression.

[a] global p value.

Table 7. Maternal characteristics of study sample and association with PTD

	Total* n=2,798	Normal gestation & birth weight n=2,456	**PTD** n=276	OR^	95% CI	p
Age						
<19	153 (5.5%)	130 (85.0%)	17 (11.1%)	1.204	.713, 2.032	.488
19 – 35	2266 (81.0)	2003 (88.4)	213 (9.4)	[1.00]	Referent	.255[a]
>35	379 (13.5)	323 (85.4)	46 (12.1)	1.330	.948, 1.867	.099
Race						
White	2062 (73.7)	1842 (89.4)	181 (8.8)	[1.00]	Referent	.001[a]
Black	596 (21.3)	490 (82.2)	83 (13.9)	1.680	1.273, 2.217	<.0001
Other	140 (5.0)	124 (88.6)	12 (8.6)	.973	.528, 1.793	.931
Previous Birth						
No	1212 (43.3)	1057 (87.2)	119 (9.8)	1.012	.786, 1.302	.925
Yes	1575 (56.3)	1392 (88.5)	152 (9.7)			
Marital Status						
Not married	962 (34.4)	798 (83.0)	125 (13.0)	1.665	1.295, 2.140	<.0001
Married	1830 (65.4)	1652 (90.3)	151 (8.3)			
Education Level						
≤11th grade	274 (9.8)	233 (85.0)	28 (10.2)	1.176	.771, 1.793	.451
12th or GED	587 (21.0)	490 (83.5)	76 (13.0)	1.540	1.154, 2.054	.003
Postsecondary	1915 (68.4)	1715 (89.6)	169 (8.8)	[1.00]	Referent	.013[a]
Smoking Status						
No	2344 (83.8)	2092 (89.3)	210 (9.0)			
Yes	417 (14.9)	338 (81.1)	57 (13.7)	1.613	1.179, 2.207	.003
PNC in 1st Trimester						
No	269 (9.6)	220 (82.1)	38 (14.2)	1.780	1.223, 2.591	.003
Yes	2146 (76.7)	1918 (89.4)	183 (8.5)			
History of PTD						
No	2737 (97.8)	2417 (88.4)	257 (9.4)			
Yes	61 (2.2)	39 (63.9)	19 (31.1)	4.362	2.499, 7.613	<.0001
PROM						
No	2691 (96.2)	2400 (89.3)	229 (8.5)			
Yes	107 (3.8)	56 (52.3)	47 (43.9)	8.415	5.612, 12.617	<.0001

*Independent variable totals may not equal 100% of study sample due to missing/unknown values.

^ Assessed using binary logistic regression.

[a] global p value.

Table 8 shows the proportion of each maternal characteristic within each quartile of exposure to lead and toluene. There were more women 36-50 years of age in the lowest quartiles of both lead and toluene compared to high quartiles, indicating that fewer older pregnant women were exposed to higher levels of lead and toluene. The lowest quartiles of lead and toluene also had higher proportions of married women than the higher quartiles of lead and toluene. This suggests that more married women either live farther from TRI sites or live near TRI facilities with lower lead and toluene releases. The lowest quartiles of lead and toluene each had the lowest proportion of less educated women and the highest proportion of women with college education. This would seem to indicate that a higher proportion of less educated pregnant women are exposed to higher levels of lead and toluene, while more educated women are exposed to lower levels of lead and toluene air pollution. The highest quartile for lead had the highest proportion of white women yet the lowest proportion of black women. The opposite was true for toluene. The lowest quartile of toluene had the highest proportion of white women and the lowest proportion of black women compared to the higher quartiles. This appears to indicate that many Caucasian women are living in neighborhoods exposed to higher levels of lead pollution yet areas with higher concentrations of African-American women are exposed to higher levels of toluene.

Unmarried, less educated, non-white women were more likely to be exposed to second and third level quartiles of lead exposure. Women who were exposed to lower levels of lead were more likely to be married, older, and with higher education. Similarly less educated women were more likely to be exposed to higher quartiles of toluene while those who experienced lower levels of exposure tended to be married, older, more educated and either white or other in ethnicity. Other maternal characteristics such as a previous birth, premature rupture of membranes or history of preterm delivery did not have significant associations with lead or toluene quartiles of exposure as assessed by chi square.

Table 8. Percentages of maternal characteristics by quartile of lead and toluene exposure

Quartiles of Exposure	Previous Birth (%)	PROM (%)	Hx PTD (%)	+Smoking (%)	Married (%)	PNC 1st Tri (%)	Maternal Age (%)			Education Level (%)			Race (%)		
							12-18 years	19-35 years	36-50 years	Up to 1th	12th or GED	College	White	Black	Other
Lead (lbs per year/m²)*															
1st < -5.0969	56.7	3.6	2.5	10.1	80.2	90.8	2.7	80.7	16.6	4.8	15.2	80.0	83.1	13.2	3.6
2nd -5.0969 thru -4.9586	55.0	4.7	1.9	14.3	56.0	85.9	6.7	80.2	13.1	10.7	26.2	63.1	59.7	33.6	6.7
3rd -4.9585 thru -4.7212	57.5	3.4	2.4	22.7	49.4	86.6	8.7	80.5	10.8	16.2	26.6	57.1	63.8	32.3	3.8
4th >4.7212	56.8	3.5	2.0	14.0	75.2	91.7	4.0	82.7	13.3	8.3	17.1	74.6	87.7	6.3	6.0
x^2 (p)^	.82	.54	.84	<.0001	<.0001	.001	<.0001			<.0001			<.0001		
Toluene (lbs per year/m²)*															
1st < -3.7746	54.2	3.8	2.3	11.5	80.5	92.8	2.9	82.1	15.0	6.9	13.3	79.8	89.0	4.5	6.5
2nd -3.7746 thru -3.6861	56.8	3.2	2.2	16.4	64.7	88.4	5.3	81.8	12.8	10.5	22.9	66.7	70.9	21.6	7.5
3rd -3.6860 thru -3.5317	58.4	4.9	2.5	16.6	52.9	84.7	8.4	79.5	12.2	12.7	25.3	61.9	58.6	37.9	3.5
4th > -3.5317	56.8	3.6	1.9	15.7	64.3	89.1	5.0	81.4	13.6	9.1	23.2	67.6	76.2	21.1	2.7
x^2 (p)^	.46	.37	.89	.03	<.0001	<.0001	.001			<.0001			<.0001		

* $\log_{10}$ lead and toluene values.
^ Assessed using x^2 test.

Table 9 shows the percentages of each birth outcome that occurs within each quartile of lead and toluene exposure. When examining these findings, it is important to remember these chi square tests do not take into consideration other maternal characteristics that may influence pregnancy outcomes, such as those indicated in Tables 6 and 7. The highest quartile of toluene exposure contains the largest proportion of women who experienced a normal gestation and normal birth weight pregnancy outcome (p=.014). The highest quartile of toluene also has the lowest proportion of PTD (p=.043), indicating toluene exposure as a protective factor against adverse pregnancy outcomes. Chi square tests of birth outcomes among lead quartiles did not determine any significant associations.

Table 9. Percentage PTD and Term LBW by quartile of lead and toluene exposure

Quartiles of Exposure	Birth Outcomes		
	Normal gestation & birth weight (%)	PTD (%)	Term LBW (%)
Lead (lbs per year/m^2)*			
1st < -5.0969	88.8	9.2	1.8
2nd -5.0969 thru -4.9586	87.2	10.3	2.4
3rd -4.9585 thru -4.7212	86.4	10.8	2.8
4th >4.7212	88.8	9.2	2.0
p^	.412	.676	.588
Toluene (lbs per year/m^2)*			
1st < -3.7746	88.3	9.4	2.2
2nd -3.7746 thru -3.6861	86.6	10.4	3.0
3rd -3.6860 thru -3.5317	85.9	11.9	2.2
4th > -3.5317	91.1	7.4	1.4
p^	.014	.043	.247

*$\log_{10}$ lead and toluene values.
^Assessed using x^2 test.

Binary logistic regression was used to assess term LBW and PTD and quartiles of exposure. These initial regressions were unadjusted and did not have significant findings. Regressions for term LBW and quartiles of exposure were then performed adjusting for race, marital status, education level and smoking status. PTD and quartiles of exposure regressions were adjusted for race, marital status, education level, smoking status, prenatal care utilization in the first trimester, history of preterm delivery and premature rupture of membranes. Neither unadjusted nor adjusted regressions using quartiles of exposures for lead and toluene yielded significant findings (Tables 10 and 11). The Hosmer-Lemeshow goodness-of-fit test was used for all adjusted regressions, with significance levels of 0.81 and 0.98 for lead and toluene PTD and 0.86 and 0.79 for lead and toluene term LBW, suggesting a good fit for the analysis [60].

Table 10. Unadjusted and adjusted Odds Ratios for Term LBW by quartile of exposure

Quartiles of Exposure	Total n=2,798	**Term LBW** n=63	Unadjusted OR^	Unadjusted p	Adjusted[&] OR^	Adjusted[&] p
Lead (lbs per year/m^2)*						
1st < -5.0969	771	14	[1.00]	.592 [a]	[1.00]	.994 [a]
2nd -5.0969 thru -4.9586	697	17	1.352	.409	.916	.818
3rd -4.9585 thru -4.7212	677	19	1.561	.211	.966	.928
4th >4.7212	653	13	1.098	.809	.916	.827
Toluene (lbs per year/m^2)*						
1st < -3.7746	692	15	[1.00]	.166 [a]	[1.00]	.120 [a]
2nd -3.7746 thru -3.6861	713	23	1.507	.223	1.095	.796
3rd -3.6860 thru -3.5317	693	15	.999	.997	.587	.190
4th > -3.5317	698	10	.657	.308	.512	.113

*$\log_{10}$ lead and toluene values.

^ Assessed using binary logistic regression.

[a] global p

[&] Adjusted for race, marital status, education, and smoking.

Table 11. Unadjusted and adjusted Odds Ratios for PTD by quartile of exposure

Quartiles of Exposure	Total n=2,798	**PTD** n=276	Unadjusted		Adjusted[&]	
			OR^	p	OR^	p
Lead (lbs per year/m^2)*						
1st < -5.0969	771	71	[1.00]	.677[a]	[1.00]	.738[a]
2nd -5.0969 thru -4.9586	697	72	1.134	.475	.885	.573
3rd -4.9585 thru -4.7212	677	73	1.192	.318	1.052	.812
4th >4.7212	653	60	.996	.983	1.122	.585
Toluene (lbs per year/m^2)*						
1st < -3.7746	692	65	[1.00]	.035[a]	[1.00]	.007[a]
2nd -3.7746 thru -3.6861	713	76	1.151	.430	1.005	.981
3rd -3.6860 thru -3.5317	693	83	1.313	.120	.856	.471
4th > -3.5317	698	52	.776	.193	.487	.002

*$\log_{10}$ lead and toluene values.

^ Assessed using binary logistic regression.

[a] global p

[&] Adjusted for race, marital status, education, smoking, 1st trimester prenatal care, history of PTD and PROM.

5.0 DISCUSSION

This study has shown that certain maternal characteristics such as race, marital status, education level, smoking status, prenatal care utilization in the first trimester, history of preterm delivery and premature rupture of membranes can have significant effects on birth outcomes as has been previously demonstrated [15, 59]. This analysis also indicates that subsets of the population are exposed to higher or lower levels of lead and toluene TRI releases. It is plausible that women who are exposed to higher levels of lead or toluene from TRI facilities may then be exposed to other toxic releases from those same facilities.

A greater number of women who were married, older and better educated were exposed to lower levels of lead. Similarly, married women, women with higher education levels and who are white were exposed to lower levels of toluene. This suggests that there is a clustering or neighborhoods where married, older, and higher educated women live as well as where unmarried, younger, lesser educated live in relationship to TRI facilities. Future research should consider the potential confounding effects of these three factors; considering that older women, by age alone, are more likely to be marred and better educated than their younger counterparts.

In contrast, this study found no associations between exposure to toluene or lead and adverse pregnancy outcomes. This may be due to the methods used for calculating the exposure to lead and toluene and/or related to the categorical analysis of the exposure values and the birth records. The methods used in this paper attempted to measure a crude exposure for each woman from every TRI releasing facility in the county. This method may have inadvertently decreased the measurement of exposure to a high release TRI site in close proximity if the exposure measurement from an extremely distant TRI site was remarkably low, thus assigning an overall lower exposure measurement. Additionally, the lack of significant association may be due to analyzing the exposure values in quartiles as determined in this study. Additional research should include examination proxy exposure values as continuous variables.

5.1 **LIMITATIONS**

This study assumes that if toxic chemicals are released from a TRI facility into the air then the general population, including pregnant women, is exposed to these ambient toxic releases either through direct inhalation or through ingestion of products contaminated with the toxic releases. However, there are multiple pathways of human exposure associated with the spread of contaminants such as TRI releases [55]. The methods used in this study did not include a direct measurement of exposure in the mothers or their fetuses. As with all studies involving humans, a toxic or chemical release may not be a direct exposure to a mother and her fetus. "A hazard has the potential for harmful effects, but its presence alone may not be sufficient to produce an adverse effect on the population" [38]. Only with personal air monitoring systems or by direct blood sampling of mothers in Allegheny County can researchers measure the true exposure of pregnant women to ambient toxic releases. This study attempted to use a surrogate measure of exposure, although innovative, TRI release data alone assumes the woman's exposure by default of the location of women's home residences in comparison to local TRI facilities and the quantity of lead and toluene they release.

Wind and weather patterns were not assessed in this model. Therefore, the potential effects of wind and weather on the dissipation of ambient toxic releases throughout the county could not be assessed. Wind patterns could potentially put women living in a certain direction from the TRI facility at higher risk for exposure than women living in another direction from the facility. Additionally, those women living farther away from a release sight could in fact be at higher risk for exposure depending on how wind and weather potentiates the spread of the toxic releases away from the facility that released them.

This study focused on release data from businesses and factories in Allegheny County and did not take into consideration ambient air pollution from neighboring counties and states. Future studies should consider the presence and impact of air pollution from our neighbors in the west that moves east across state lines [41].

Methods in this study did not account for all behavioral factors that could impact birth outcomes or maternal exposure to other sources of lead and toluene. For example, this study does not measure occupational exposure to lead or toluene. Nor does it measure possible abuses of toluene solvents. Future in-depth studies should include a survey of other potential exposures to the toxic releases being studied. A survey could assess maternal occupational exposure, drug or solvent misuse (sniffing glue), as well as temporal assessments such as time spent outside the home when a women is more likely to be exposed to facility air pollution and duration living at the residence cited in the birth record. The current study assumes that mothers lived at the home address provided on the birth certificate throughout 2003 and that all pregnant women spent the same amount of time indoors or out-of-doors in their communities.

TRI data is only available in pounds per year. This study makes the assumption that the releases of lead and toluene were consistent throughout the year and does not determine exposure measurements at a daily, monthly or trimester level. This study assumes that the maternal exposure is consistent throughout the duration of her months of pregnancy in 2003 and that exposure during one trimester of the pregnancy may be equally harmful as exposure during another trimester of the pregnancy.

Strengths of this study include using individual longitude and latitude coordinates of birth mothers rather than aggregated birth outcome rates at the census track level. This allowed for each woman to have an individually assigned exposure measurement for analysis independent of others. Zandbergen and Chakraborty strongly recommend using individual geographic locations – determined with longitude and latitude and analyzed with GIS – rather than data aggregated at the census tract or even block level as this allows for more robust exposure calculations. Additionally "the use of individually geocoded locations provides a more accurate characterization of the exposed population and more reliable comparisons among subgroups" [58].

An additional strength of the study includes limiting the analysis of birth records to those births which occurred in January through March of 2004. This ensured that women's exposure time periods occurred during five to nine months of pregnancy in 2003. For the analysis of LBW as an adverse birth outcome, this study limited the confounding effect that prematurity can have on birth weight by including only term LBW records in the analysis.

5.2 IMPLICATIONS FOR FUTURE RESEARCH

Future research using TRI release data and GIS software should take into consideration other useful spatial functions of the GIS software. For example, clusters of births within certain neighborhoods or clusters of births near certain TRI facilities should be further analyzed for similarities and differences within the cluster as well as compared to other births not part of the cluster. This may help determine directional impact of TRI releases on neighboring groups of women.

Additionally, GIS is a useful tool for analyzing socioeconomic indicators of health. Utilizing census track data based on the location of home residence can provide other useful socioeconomic information such as household income, access to personal automobile and receipt of social security income or assistance programs. Other studies used geocoded maternal address imbedded within census track socioeconomic data to determine community-level effects on preterm birth [61]. This study used maternal education level as a proxy measurement for socioeconomic status because income is not available in the birth data. Using the maternal census tract information – determined by maternal zip code or by longitude and latitude data – could be useful in determining other socioeconomic characteristics in relation to birth outcomes or for neighborhood proximity to a TRI facility if individual measurements are deemed insufficient.

Future studies should also take into consideration the cross over or cumulative effect of known maternal characteristics. For example the interplay between race, education level, income and their separate and synergistic effects on pregnancy health and birth outcomes. In addition to this individual factors, neighborhood level factors may play their own role in the health of the woman and her pregnancy outcome. It is important to remember that poor communities frequently suffer environmental and social hazards that are unique to their area. "Such marginalized communities share much more in common including unemployment, substandard housing, inadequate health care, lack of transportation, culture and/or family structure." Poor birth outcomes may be a function of the local neighborhood environment. Future research must attempt to understand how the local environment combines with the ethnic identity of the neighborhood and socioeconomic status as it influences health, morbidity and mortality [62].

Furthermore, future studies should also investigate if certain neighborhoods are at an increased risk for exposure to TRI releases. Determining if certain neighborhoods are in closer proximity to multiple TRI facilities or if weather patterns contribute to an increased exposure in certain neighborhoods would enable interventions at the individual and neighborhood level.

Some studies that use air monitoring data break up the exposure time periods by trimester of pregnancy. This method is useful in investigating the impact of the exposure on fetal development during different trimesters of pregnancy. Such a model could be used with TRI data. TRI data is reported as an annual release, by dividing the total pounds released per year by 365, this resultant 'daily dose' could be used to calculate a mother's exposure per gestational week. Using such weekly doses would be helpful when comparing gestational lengths of pregnancy as when comparing term versus preterm deliveries.

The next step for this research is to compare TRI lead release data with local air monitoring data for ambient lead measurements. Comparing the two sources of lead information could help refine methods for determining maternal exposure to ambient lead, leading to better analysis of lead's impact on birth outcomes.

Most importantly, research is needed to understand the relationship of air pollution to birth outcomes. This research may lead to interventions or policies which aim to reduce exposure to possible sources of pollution and known toxic substances. GIS can be a powerful tool not only in obtaining environmental exposure measurements, but also in spatial analysis of the data's geographic particularities. Ideally, as others have done, applications of GIS should not only link hazards, exposure, and outcomes, but should also take the final steps toward interventions to address the health problem [55].

6.0 CONCLUSIONS

This study is the first to investigate TRI release data and birth outcomes in Allegheny County, Pennsylvania. This study aimed to establish a maternal exposure measurement based on her proximity and the quantity of release from all TRI sites in the county. Consistent with other findings, this study demonstrated the significant impact that specific maternal characteristics can have on individual pregnancy outcomes. These characteristics include maternal race, marital status, and smoking status, all significant factors effecting pregnancy outcomes. While the influence of maternal characteristics on birth outcomes is important to understand, these characteristics alone do not explain Allegheny County's continued high PTD and LBW rates. Therefore, this study attempted an innovative approach to explore the impact of our neighborhoods and industries on the health of the population.

In conclusion, air pollution resulting from local industries should be further investigated to determine the impact on maternal and fetal health. The TRI database and birth certificate records are useful sources of data for such studies. This research provides an example and basis for future studies to further investigate maternal exposure measurements to locally produced air pollution and considerations for including both neighborhood and individual level factors which may contribute to the exposure measurement and/or the birth outcome. Use of GIS to analyze data sets proves helpful in considering spatial relationships and geographical clustering of both births and toxic release sites that otherwise could not be evaluated using typical statistical software package. In order to fully understand Allegheny County's persistently high rates of preterm delivery and low birth weight, research must better examine the physical environment in which women live, conceive and carry their pregnancy.

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